MECHANICAL RESPONSES AND VISCOELASTIC PROPERTIES OF ASPHALT MIXTURES UNDER HEAVY STATIC AND DYNAMIC AIRCRAFT LOADING

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- U.S. Army Corps of Engineers
- NJDOT, DelDOT, RIDOT

PROBLEM STATEMENT

Increasing Flight Demand

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Larger Aircraft

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Stronger Flexible Pavements

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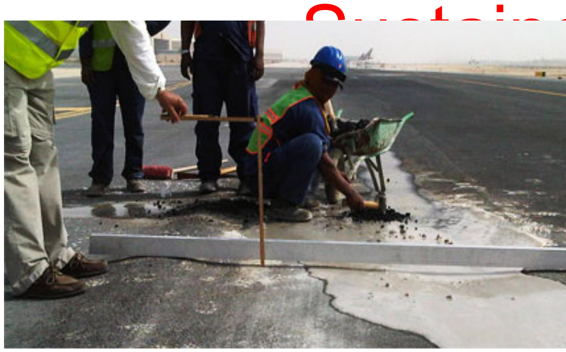

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mixtures currently used in the highway sector under heavy static and dynamic aircraft loading

Doha International Airport

http://www.imm.ch

OBJECTIVES

- Measure flow time, viscoelastic properties, and number of cycles to failure of a broad range of asphalt mixtures
- Determine mechanical responses of pavement surface under static and dynamic aircraft loading (FEA)
- Determine the relative pavement life of the mixtures

RESEARCH APPROACH

Literature Review	• Identify current and emerging asphalt mixtures • Similar studies
Material Selection	• Broad range of asphalt mixtures (including 6 mixtures)
Laboratory Testing	• Flow Time in AMPT equipment • Number of cycles to failure measure with overlay tester • Compare mixtures based on laboratory performance
FEA Analysis	• Compare mixtures based on mechanical responses under heavy static and dynamic aircraft loading
Relative Pavement Life	• Compare mixtures based on predicted life

CURRENT FLEXIBLE PAVEMENT MIXTURES

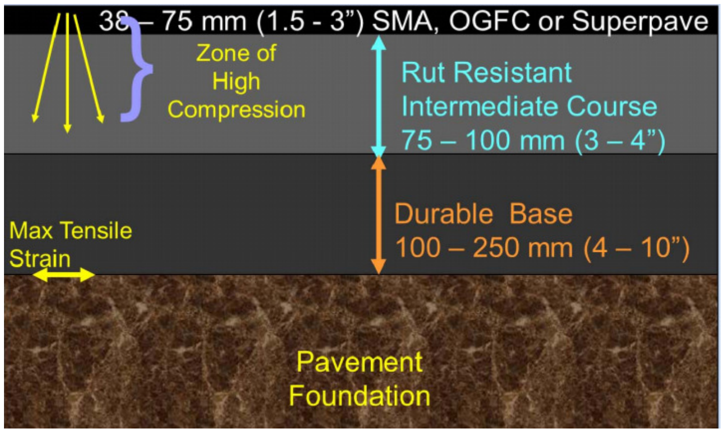
- **FAA P401 Specifications**
  - Specifies gradation and other test properties
  - Dense graded HMA mixtures (PG 76-22 or 64-22)
  - Aircraft loadings greater than 12,500 lbs

- **Modified asphalt mixtures to improve performance**
  - Hot Mix Asphalt (HMA) with Polymer Modified Binders – Logan International Airport
  - Reclaimed Asphalt Pavement (RAP) – Logan International Airport
  - Stone Matrix Asphalt (SMA) – Indianapolis International Airport

EMERGING ASPHALT MIXTURE TECHNOLOGIES

- **Warm-Mix Asphalt (WMA)**
  - Logan International
  - Steven Anchorage International
  - O'Hare International
- **Performance-based mixtures**
  - Bottom Rich Intermediate Course (BRIC)

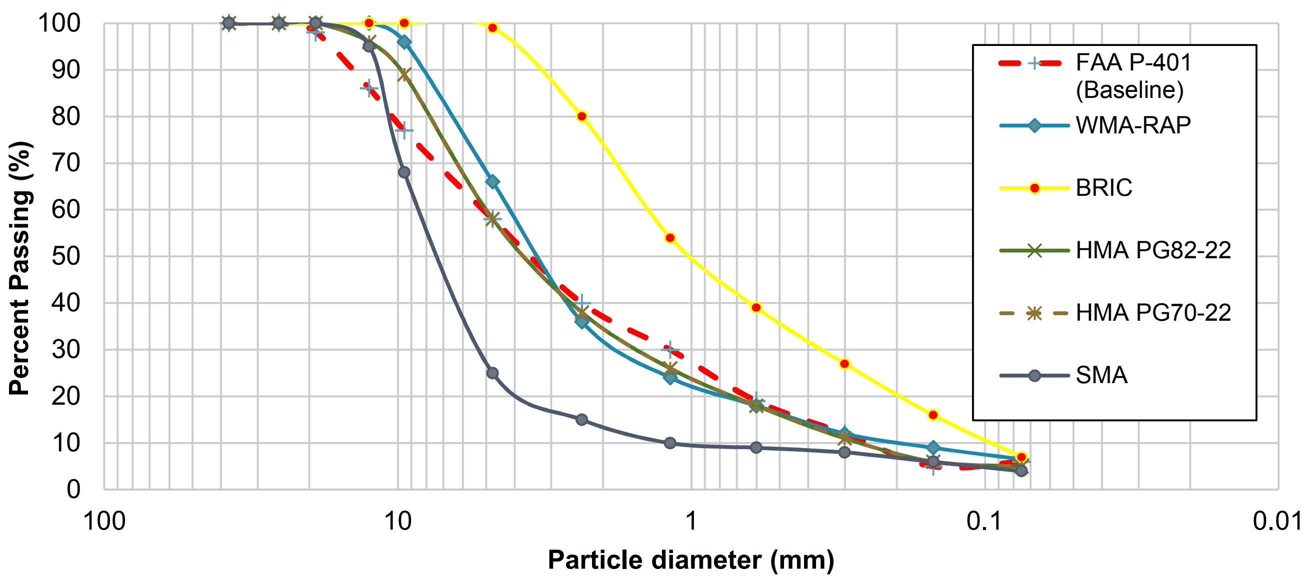
BRIC →



http://www.airporttech.tc.faa.gov

MIXTURE PROPERTIES

Mixture Design Properties	Asphalt Mixtures Tested (6 total)					
	FAA P-401 (Baseline)	WMA-35% RAP	SMA	HMA PG82-22	HMA PG70-22	BRIC
PG Grade	76-22	64-28	76-22	82-22	70-22	70-28
Asphalt Content (%)	5.02	5.25	4.87	5.41	4.83	8.40



AIRFIELD PAVEMENT ANALYSIS

FAA National Airport Pavement Test Facility Construction Cycle -1

Material	Thickness (mm)	Density (kg/m3)	Poisson's Ratio	Elastic Modulus (MPa)
Asphalt Surface	127	-	-	Estimated from creep data or obtained from laboratory testing
Stabilized Asphalt-Treated Base P-401	127	2,403	0.35	2,758
Subbase P-209	216	2,162	0.35	261
Medium Strength Subgrade	2,438	1,490	0.4	72

3D FEA - ABAQUS

RUTTING POTENTIAL

https://faapaveair.faa.gov

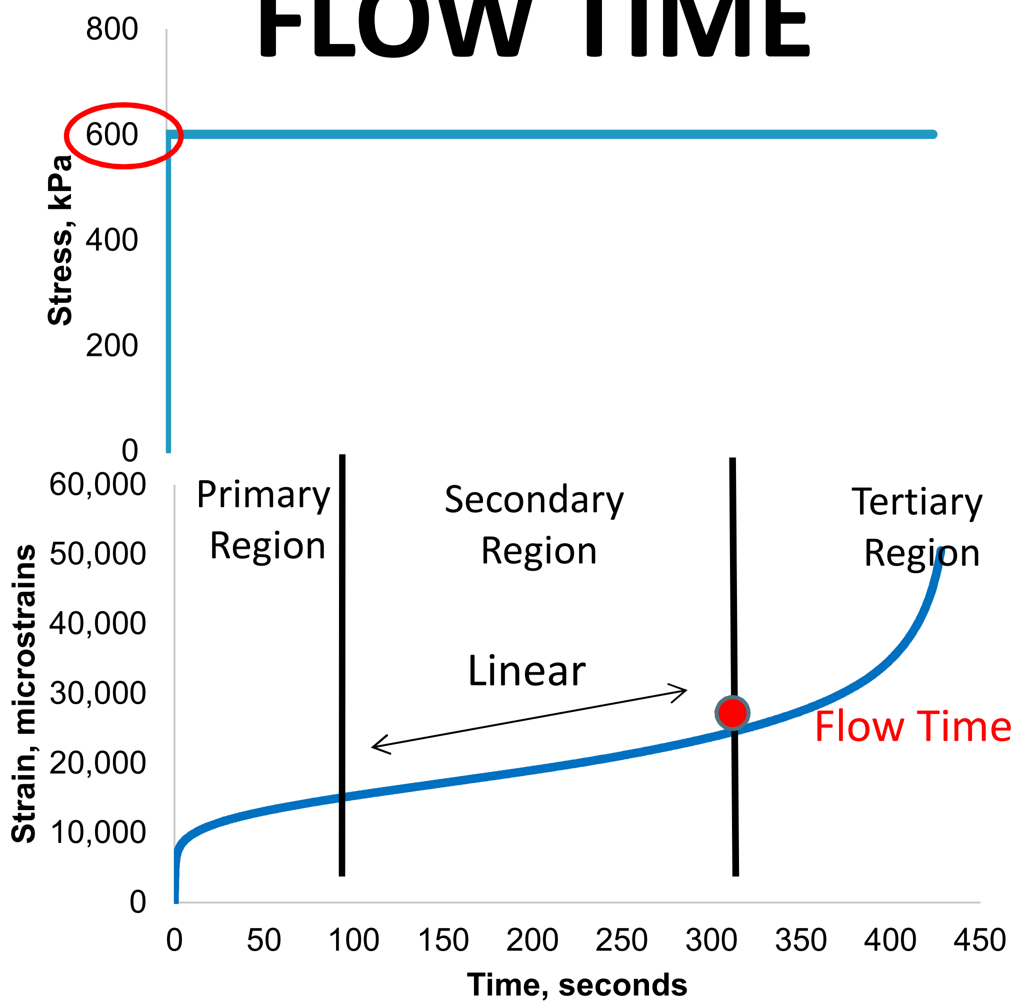
https://faapaveair.faa.gov

https://enr.construction.com

LABORATORY TESTING
FLOW TIME

52.5º C

Average pavement temperature at 50mm into pavement surface (LTTPBind)

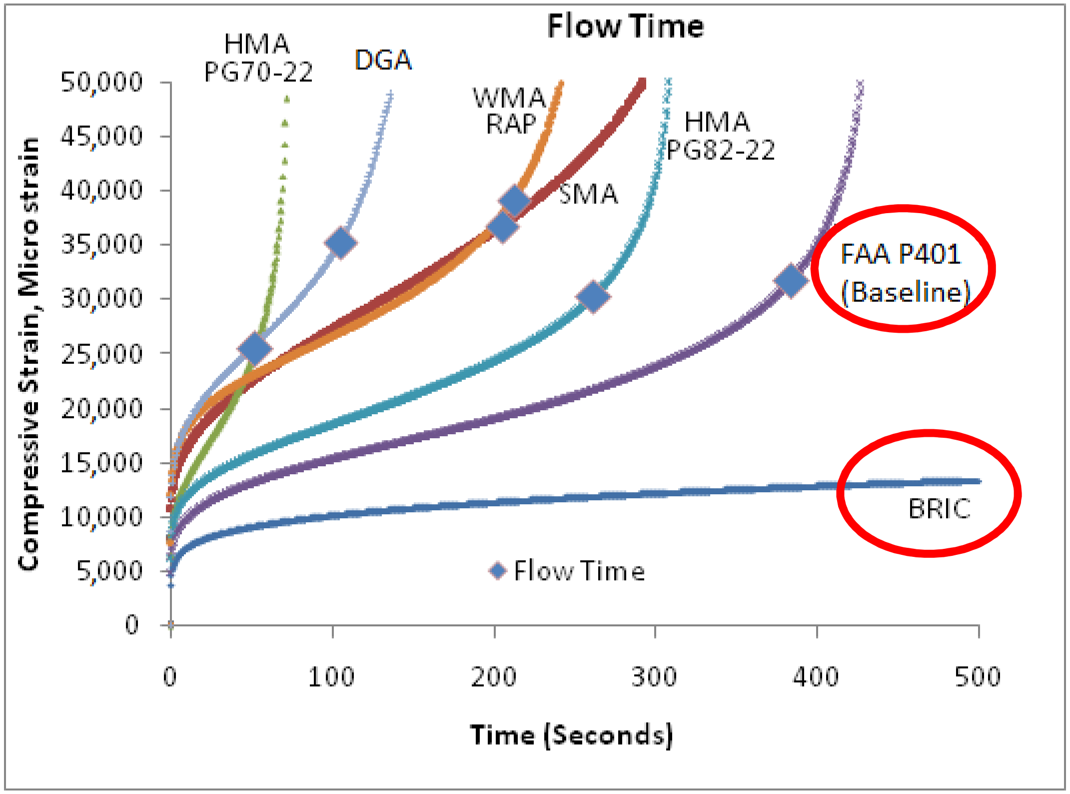


Flow Time Test - AASHTO TP79-11

Specimen Preparation - AASHTO PP 60

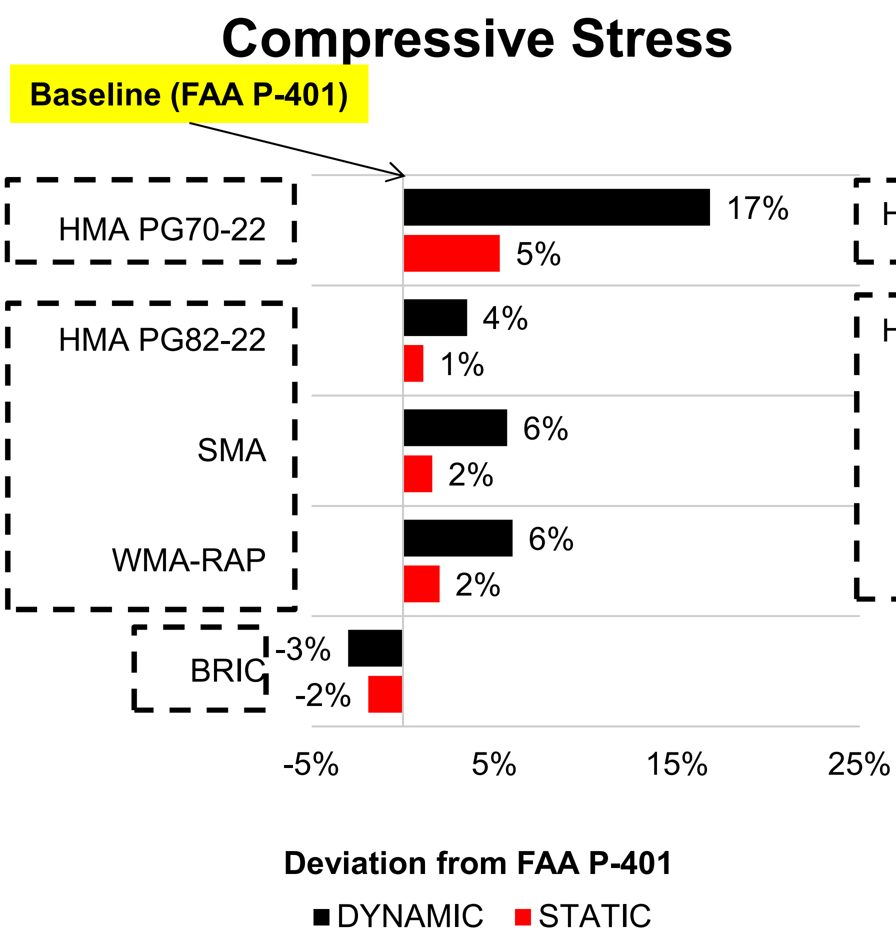
FLOW TIME TEST RESULTS

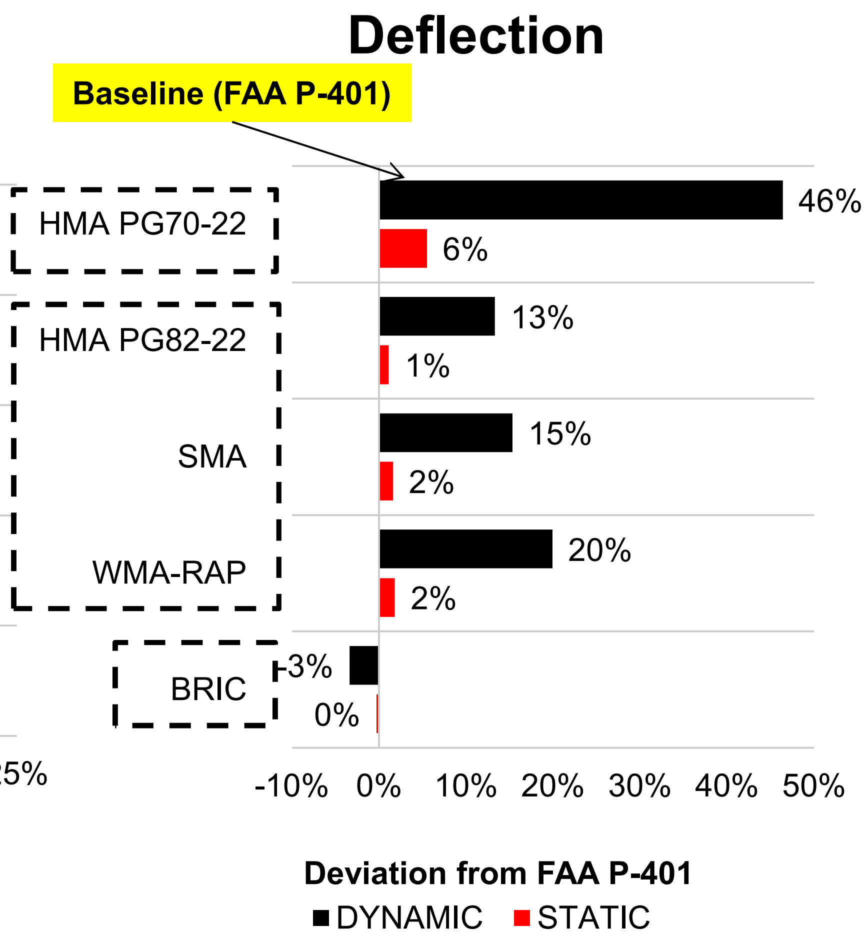
Flow time curve was utilized to determine the viscoelastic properties (creep data)



Asphalt Mixture	*Flow Time (sec)*	*Microstrains*
FAA P401 (Baseline)	385	31,721
WMA-35% RAP	213	39,202
SMA	206	36,808
HMA PG82-22	262	30,302
HMA PG70-22	53	25,424
BRIC	4,011	39,661

MECHANICAL RESPONSES (ABAQUS ™)





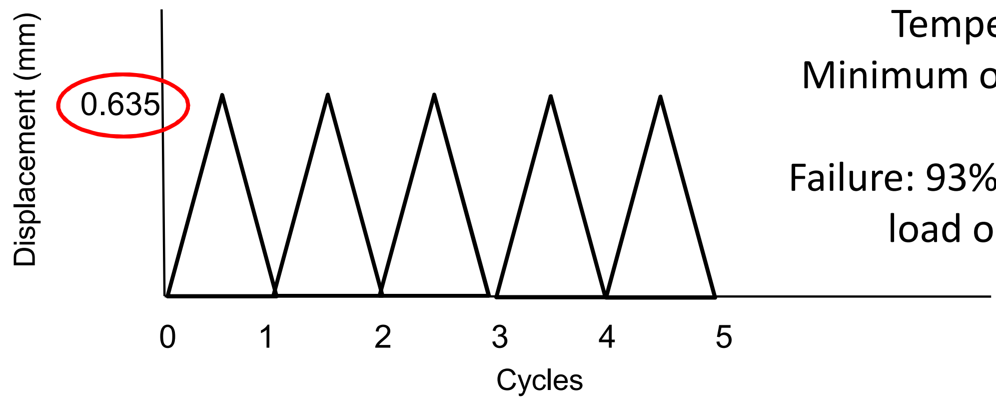
FATIGUE CRACKING POTENTIAL

https://faapaveair.faa.gov

https://faapaveair.faa.gov

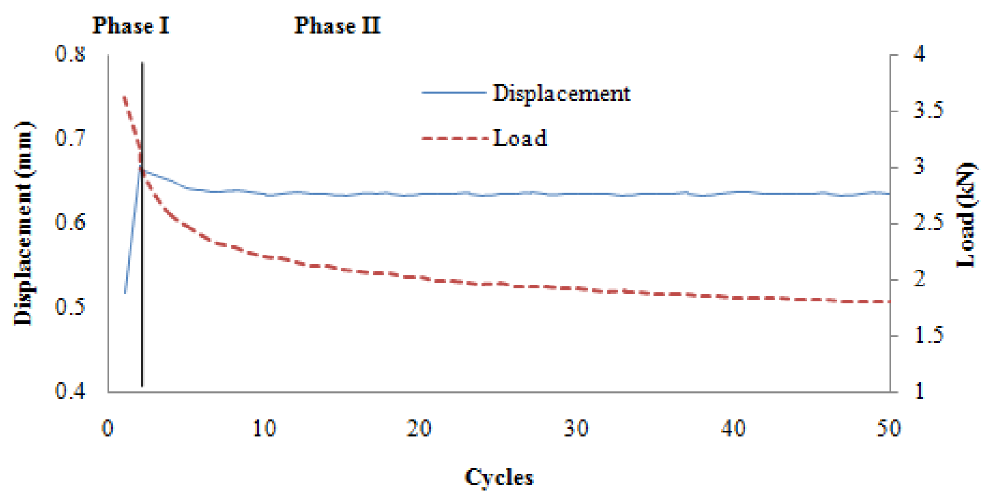
https://faapaveair.faa.gov

LABORATORY TESTING
OVERLAY TESTER



Temperature: 25° C
Minimum opening: 0.625 mm

Failure: 93% reduction of initial load or 1,200 cycles



TxDOT test procedure Tex-248-F
AMPT equipment

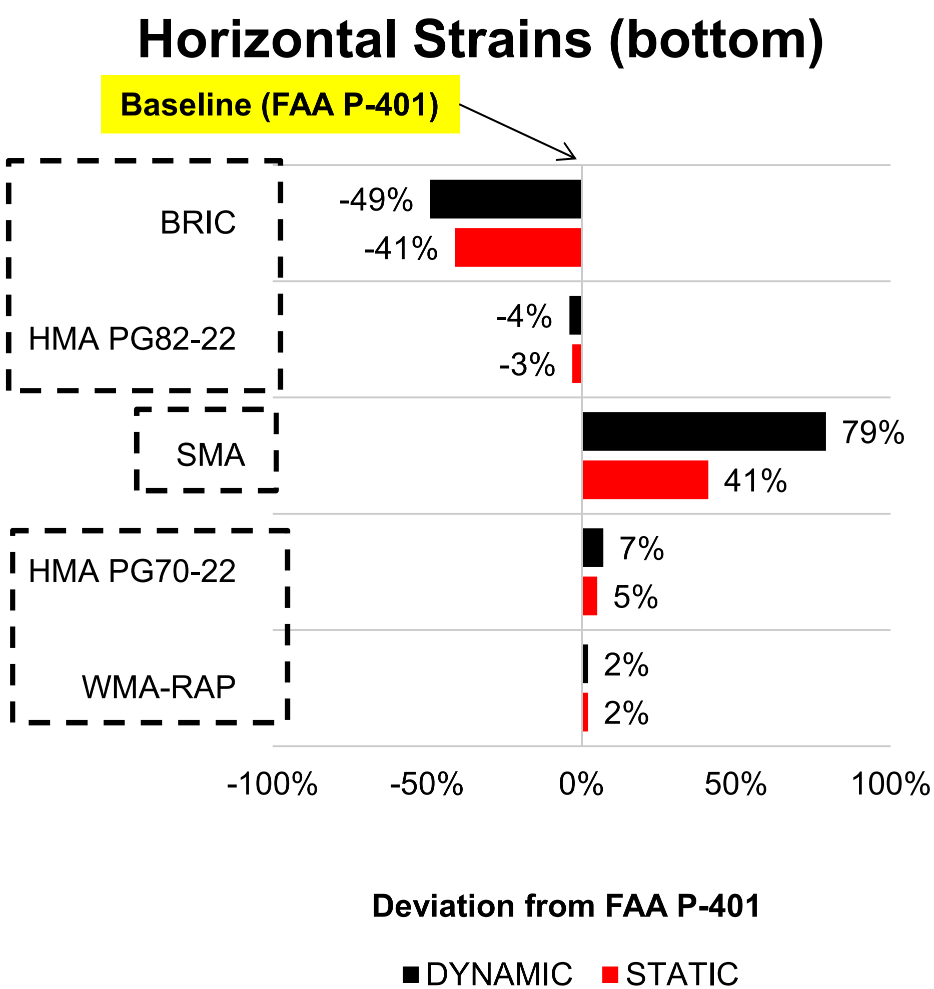
OVERLAY TEST RESULTS

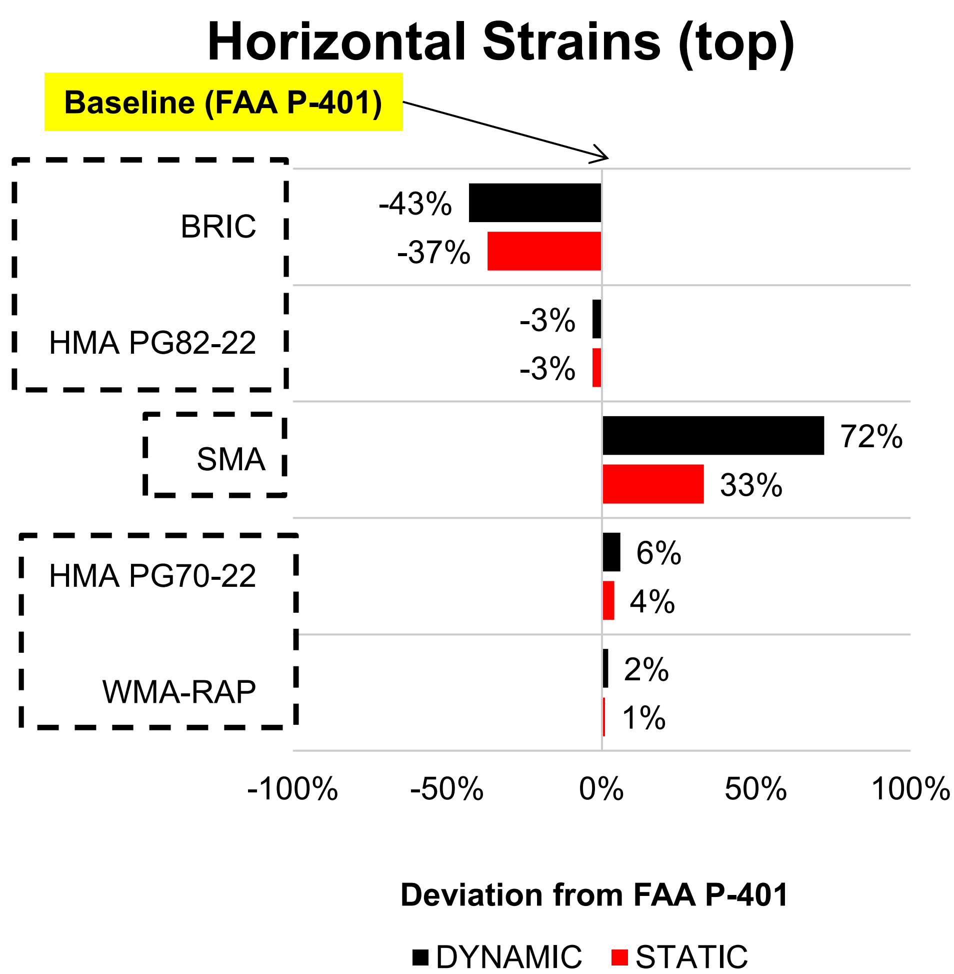
Asphalt Mixture	Sample No.	Initial Load (kN)	Final Load (kN)	Reduction (%)	Load Cycles to Failure
FAA P-401	1	3.414	0.923	83	1,200
	2	3.408	0.915	81	1,200
WMA-RAP	1	2.412	0.756	93	728
	2	2.414	0.444	93	640
SMA	1	3.124	1.039	93	255
	2	3.883	1.004	93	192
BRIC	1	1.987	0.773	77	1,200
	2	2.129	0.719	78	1,200

Failure Criteria

- 300 cycles - dense graded mixtures
- 750 cycles - fine graded crack-resistant mixtures

MECHANICAL RESPONSES (ABAQUS ™)

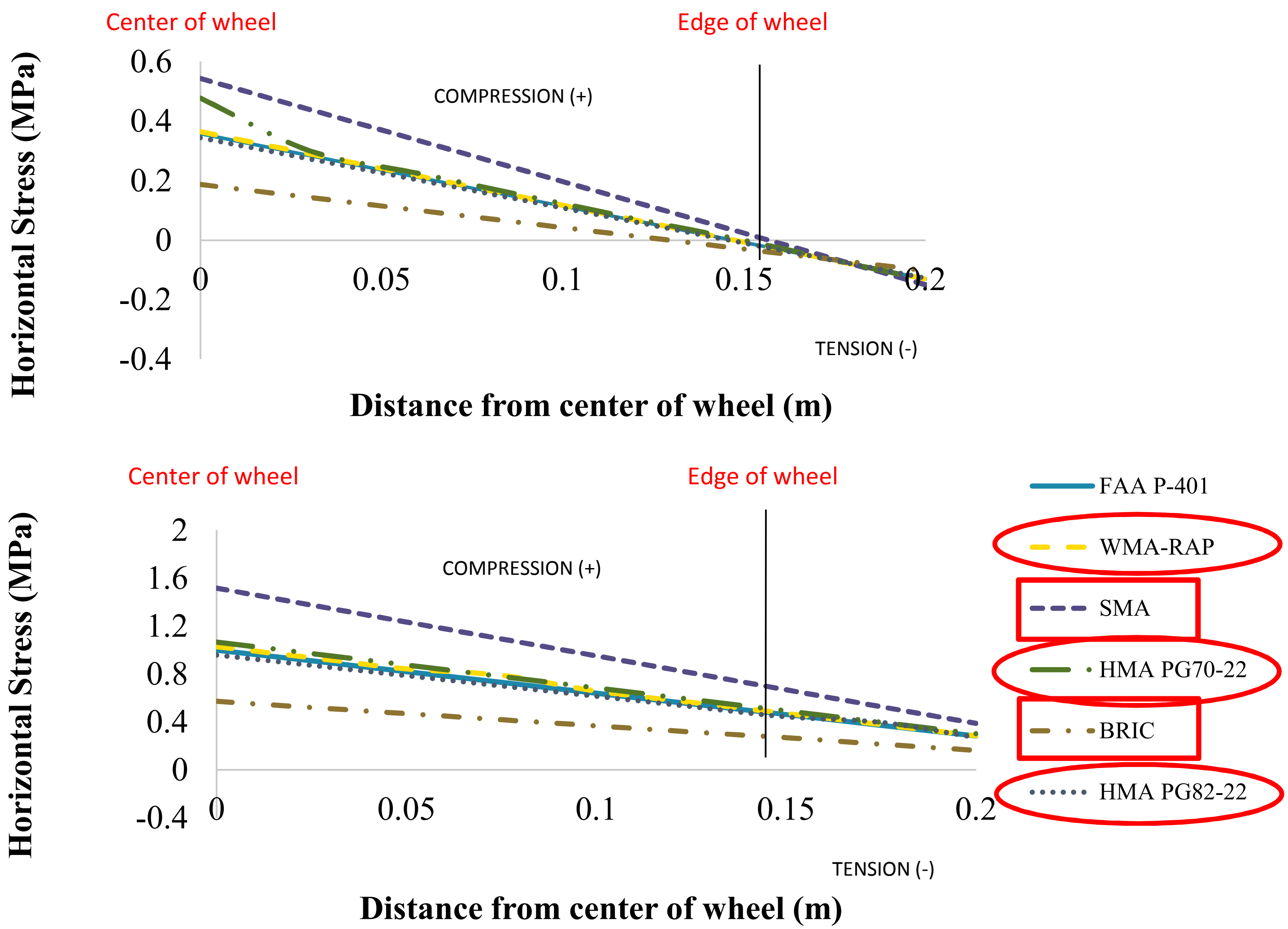




TENSILE STRESSES FROM CENTER TO EDGE OF WHEEL

STATIC

DYNAMIC



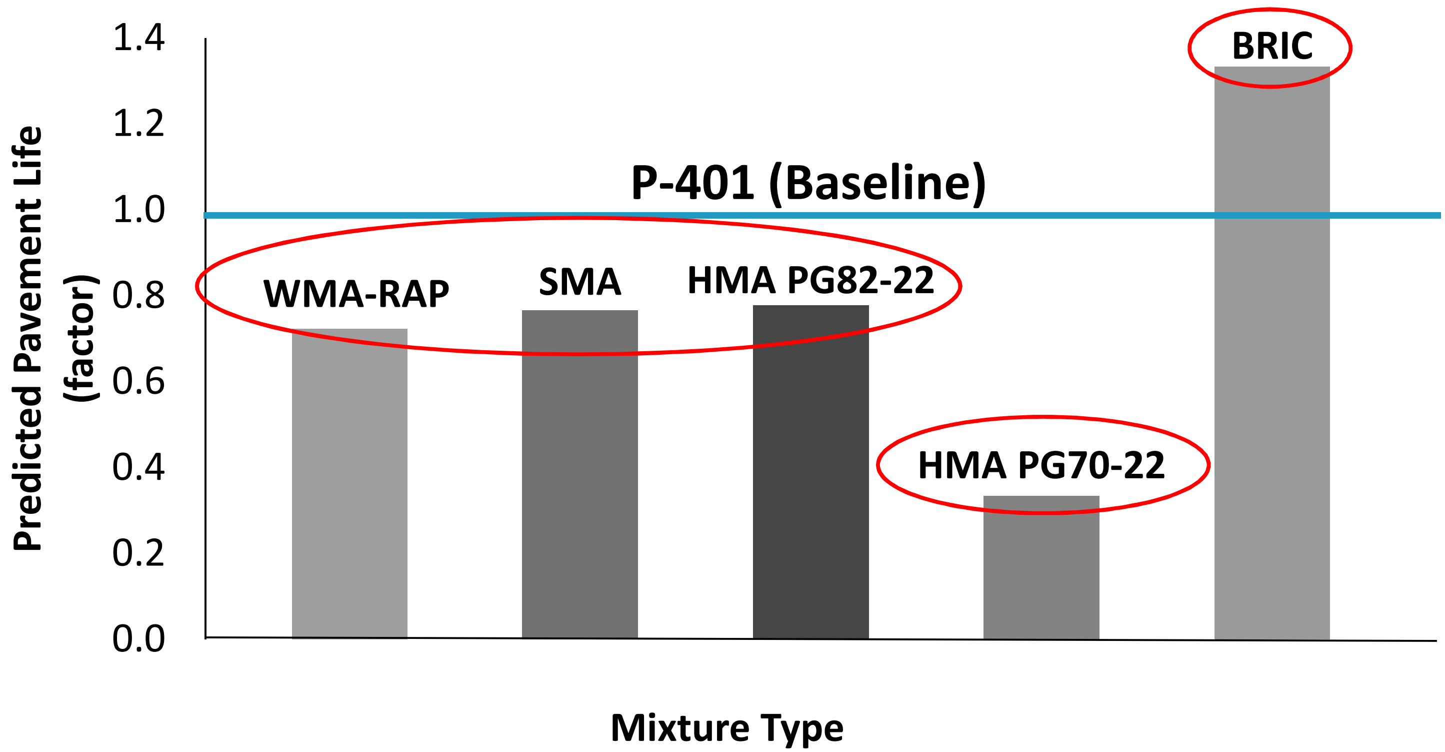
FAARFIELD

- **Distress model**
  - Compressive strains - top of subgrade
  - Tensile strains - bottom of HMA surface
- **Aircraft load**
  - Gross weight 181,437 kg; tire pressure 1,379 kPa

Temperature	Asphalt Mixtures - |E*| (MPa)					
	Baseline (FAA P-401)	WMA-35% RAP	SMA	HMA PG82-22	HMA PG70-22	BRIC
52.5ºC	103.7	57.0	60.4	81.5	77.6	135.4
25ºC	1,996	1,935	851	2,128	1,822	1,996

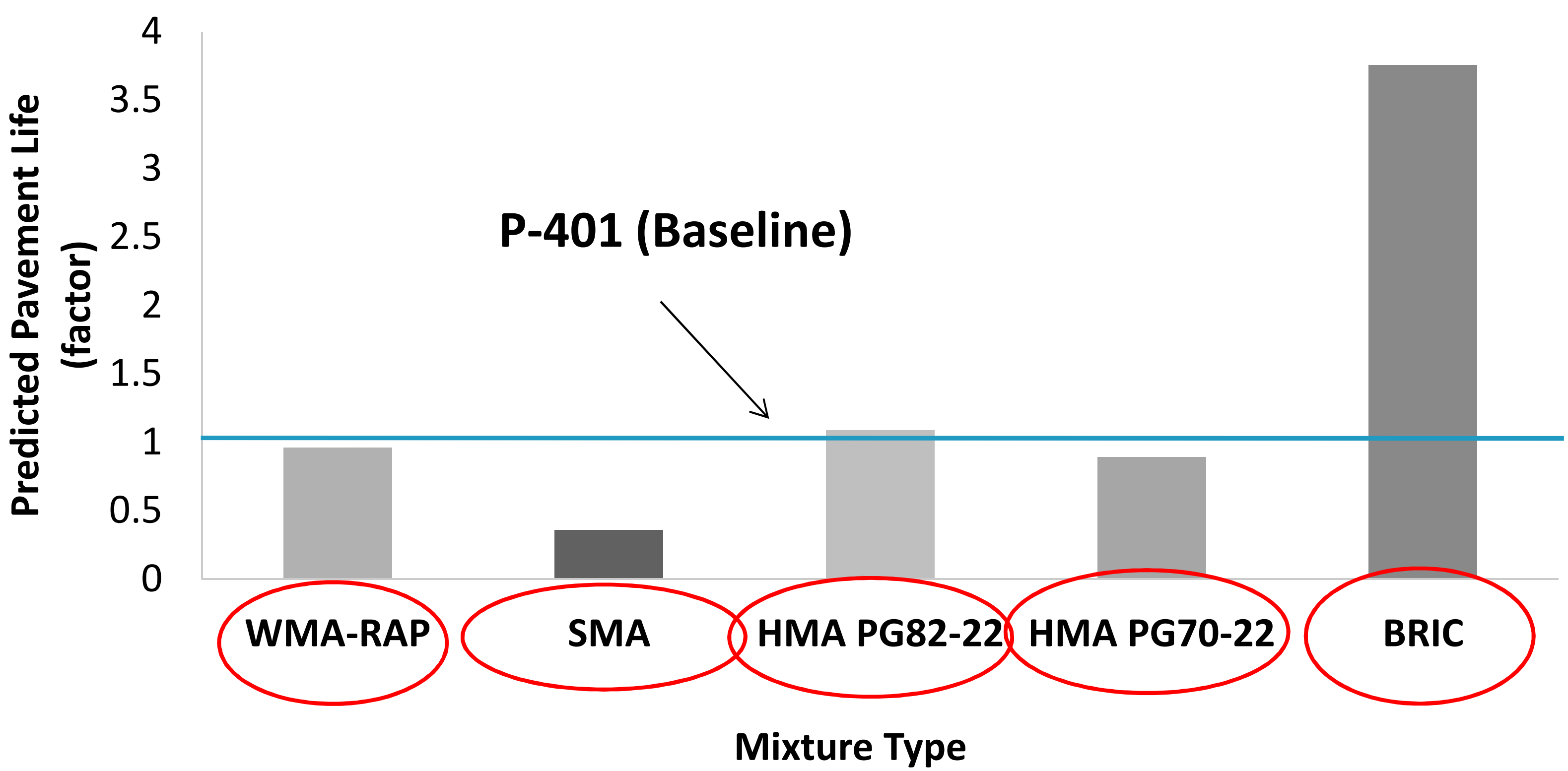
RELATIVE PAVEMENT LIFE (FAARFIELD)

Stiffness measured at 52.5°C



RELATIVE PAVEMENT LIFE (FAARFIELD)

Stiffness measured at 25°C



CONCLUSIONS

Potential for alternative mixtures to be used as surface lift in airfield taxiways and aprons

RUTTING POTENTIAL	FATIGUE CRACKING POTENTIAL
BRIC	**BRIC**
	HMA PG82-22
P-401	**P-401**
WMA-RAP	**WMA-RAP**
SMA	**HMA PG70-22**
HMA PG82-22	
HMA PG70-22	**SMA**

Larger variety of aircraft wheel configurations

Field evaluation to validate analysis

Expand to include more mixtures and explore different binders

Thank you!

http://www.airplane-pictures.net

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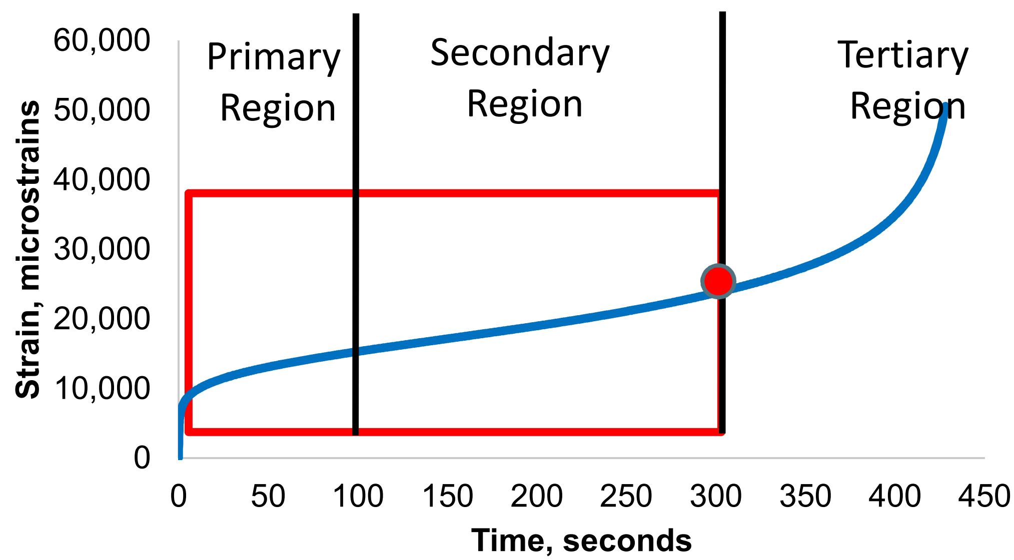
SIMILAR STUDIES

Author (year)	Title	Finding
Rushing, Mejías-Santiago, Doyle (2013)	ASSESSMENT OF WARM MIX ASPHALT (WMA) FOR HEAVY TRAFFIC AIRFIELDS	Based on laboratory performance test data, WMA is a viable alternative to HMA for wearing surfaces on airfields.
Wang, Al-Qadi, Portas, Coni (2013)	THREE-DIMENSIONAL FINITE ELEMENT MODELING OF INSTRUMENTED AIRPORT RUNWAY PAVEMENT RESONSES	A 3D finite element model was used to model and analyze an instrumented runway at the Cagliari Elmas airport to determine pavement responses under moving aircraft moving tire loading.
Prowell, Watson, Hurley, Brown (2010)	EVALUATION OF STONE MATRIX ASPHALT (SMA) FOR AIRFIELD PAVEMENTS	Based on literature review, performance of in-service airfields, and the laboratory testing, SMA performs similar or superior to dense-graded P401 mixes in terms of rutting susceptibility and deicer resistance.

ABAQUS INPUT PARAMETERS



Prony Series

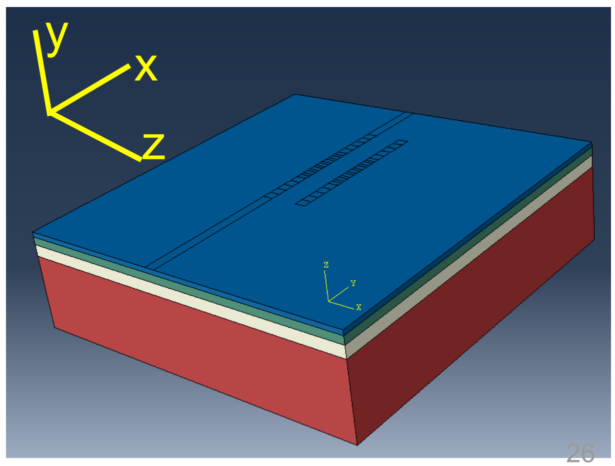
$$J(t) = A + B\left(1 - e^{\frac{-t}{C}}\right) + D\left(1 - e^{\frac{-t}{E}}\right)$$

ABAQUS MODEL

- 3D reduced integration elements (C3D8R)
- Finer mesh under load path
- Boundary conditions:
  - Constrained along the bottom in all directions
  - Sides restrained in movement in the x- and z-direction
- Layers:
  - Surface layer – viscoelastic or elastic
  - Base, subbase, and subgrade – elastic
- Size: 14m (L); 3m (H); 14m (W)

KENLAYER vs ABAQUS (Static Analysis)
~ 4% error
between closed form solution and ABAQUS

ABAQUS ™ Model



MECHANICAL RESPONSES (ABAQUS ™)

STATIC

Mixtures	Stress (kPa)	Deflection (mm)	% deviation from P401	
			Stress	Deflection
FAA P401 (Baseline)	1,334	3.030	N/A	N/A
BRIC	1,309	3.020	-1.90%	-0.30%
WMA-35%RAP	1,364	3.084	2.00%	1.80%
SMA	1,355	3.078	1.60%	1.60%
HMA PG82-22	1,349	3.063	1.10%	1.10%
DGA	1,373	3.084	2.90%	1.80%
HMA PG70-22	1,404	3.198	5.30%	5.50%

MECHANICAL RESPONSES (ABAQUS ™)

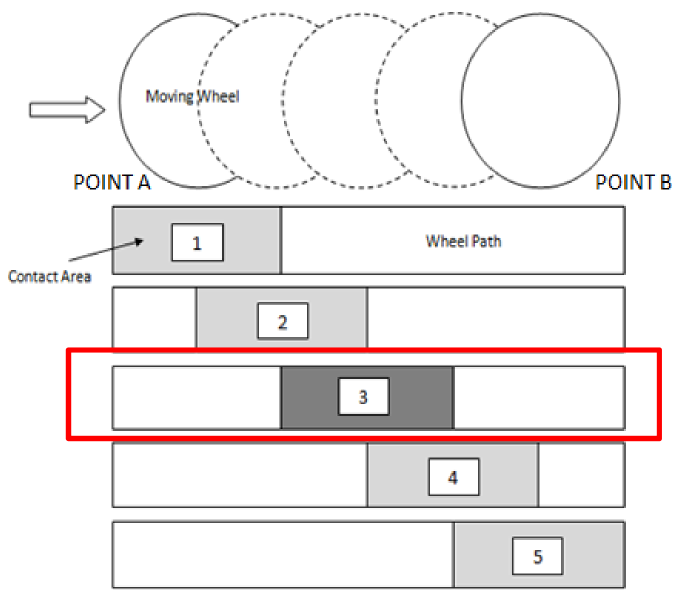
DYNAMIC

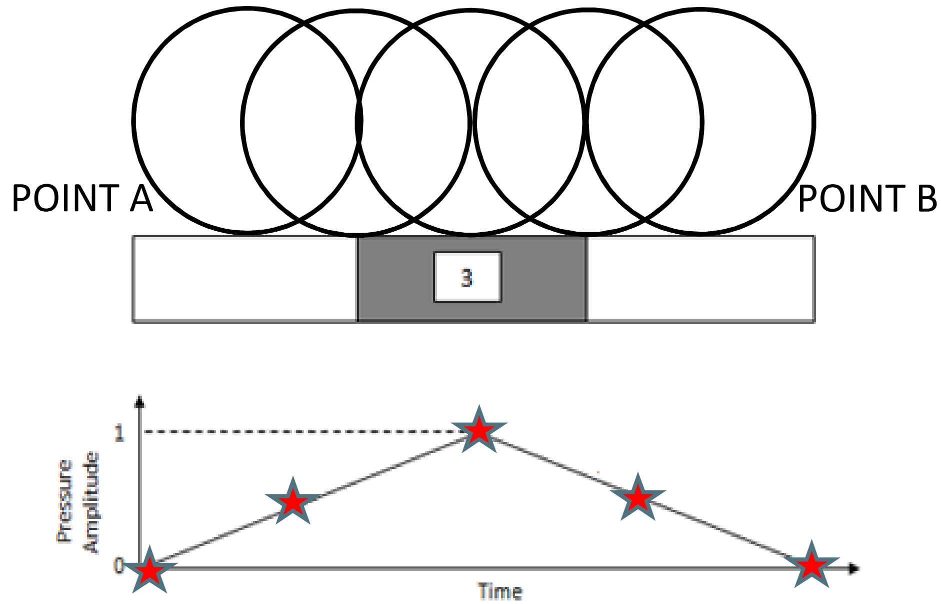
Mixtures	Stress (kPa)	Deflection (mm)	% deviation from P401	
			Stress	Deflection
FAA P401 (Baseline)	1,037	1.046	N/A	N/A
BRIC	1,006	1.011	-3.00%	-3.40%
WMA-35%RAP	1,114	1.265	6.00%	19.90%
SMA	1,096	1.207	5.70%	15.30%
HMA PG82-22	1,073	1.186	3.50%	13.30%
HMA PG70-22	1,211	1.532	16.80%	46.40%
DGA	1,162	1.288	12.00%	23.10%

MECHANICAL RESPONSES (ABAQUS ™)

Asphalt Mixtures	3D FEA (ABAQUS ™)							
	Static Load				Dynamic Load			
	ε_{bottom} ($\mu\varepsilon$)	ε_{top} ($\mu\varepsilon$)	% variation from P-401		ε_{bottom} ($\mu\varepsilon$)	ε_{top} ($\mu\varepsilon$)	% variation from P-401	
			ε_{bottom}	ε_{top}			ε_{bottom}	ε_{top}
FAA P-401 (Baseline)	1,165	291	Baseline	Baseline	211	56	Baselin e	Baseline
WMA-RAP	1,183	295	2%	1%	216	58	2%	2%
SMA	1,641	387	41%	33%	377	98	79%	72%
HMA PG82-22	1,128	283	-3%	-3%	202	55	-4%	-3%
HMA PG70-22	1,218	302	5%	4%	225	60	7%	6%
BRIC	684	182	-41%	-37%	541	32	-49%	-43%

DYNAMIC LOADING





Pressure amplitude on **Element 3**
as wheel moves from A to B